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Biodiversity and water health status of four rivers in the East Cameroon region

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Abstract

A study on the biodiversity and health status of the waters of four stream in the East Cameroon region was conducted from December 2018 to December 2019. Physicochemical parameters were measured following Rodier's recommendations, while benthic macroinvertebrates were collected following the multihabitat approach. The physicochemical analyses show that the waters of the streams in the East Cameroon region are well oxygenated (70.16%), slightly acidic (5.18 UC), with low values of nitrogen and phosphate compounds (0.48 mg/L) indicating low litter decomposition. A total of 12558 benthic macroinvertebrates were collected on the 4 streams studied and divided into 3 phyla, 5 class, 12 orders, 33 families and more than 56 genera and species. The largest number of organisms collected belonged to the class Hexapoda, which represented 58.87% of relative abundance, followed by Malacostraca (33.34%). The order Decapoda dominates with 33.34% relative abundance, followed by Dictyoptera with 27.55% relative abundance. These two orders are dominated by the families Atyidae and Blaberidae in the majority of the stream studied. The Shannon and Weaver (H') and Piélou equitability (J) indices show a high diversity of taxa in the stream studied, with the exception of station Sen3, where conditions seem to be very unfavourable for the development of benthic macroinvertebrates, as indicated by the physicochemical results. The Sörensen index reveals that the tax collected in the majority of the stations are inversely similar to those collected in the Sen3 station. In short, the stream of the East Cameroon region has a fairly rich and diversified population of benthic macroinvertebrates, thus testifying to the relatively good ecological quality of the water, despite the observation made at the Sen3 station, which shows the beginning of pollution of these waters.

Keywords: Benthic macroinvertebrates; Plinthic Ferralsols; Forest streams; Nyong River; Abong-Doum

1. Introduction

The preservation of water quality is a major issue for the sustainable management of the environment, but also for biodiversity. Whether it is considered as a material or a medium, water is an essential element for the development of all forms of life on earth. In fact, water conditions the health of humans and ecosystems in addition to its fundamental role in the development of countries where it is used for physiological, agricultural, industrial and energy purposes (42). Human activities, marked by the intensification of urbanisation, agriculture and industry, are at the origin of a considerable production of solid and liquid waste that degrades water quality (59). Its monitoring must be done through the permanent evaluation of its health status by reliable and adequate indicators including biological indicators (19; 7). Among these bioindicators, benthic macroinvertebrates, due to their great diversity, variable life span, wide

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distribution, sedentary nature, variable tolerance to pollution and habitat degradation (40), are excellent bioindicators of the health of hydrosystems (26). They are therefore increasingly used to assess the overall health of ecosystems (28; 6; 58). The main advantage of using these benthic macroinvertebrates is that they are sensitive to physicochemical variables and environmental disturbances (1).

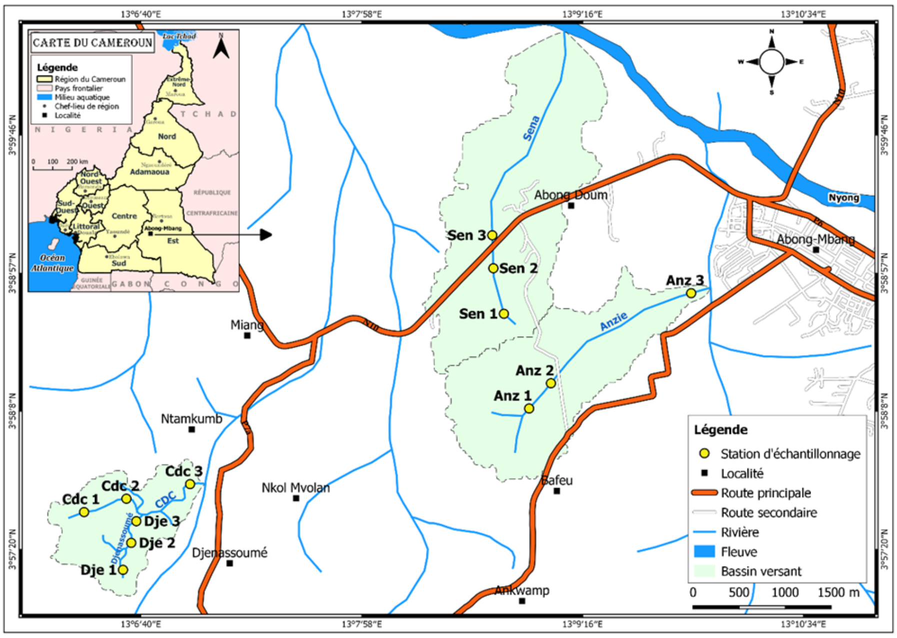
In Cameroon, a few studies have been conducted on the biodiversity of BIMs in lotic environments. These are the works of BIRAM A NGON (9) in the streams of the Centre region, TCHAKONTE (55) in the urban and forest streams of the Littoral region, KENGNE (30) in the Western region, ENAH ACHUO (20) in the North West region, NWAHA (46) in the South West region, NYAMSI (47) in the South and MADOMGUIA (33) in the Far North. However, in the Eastern region, despite the work of YOGBA (58), the MIB community remains little known. This study, which is a contribution to the knowledge of the benthic macroinvertebrate fauna of four forested streams in the Eastern Region in relation to the quality of its waters, aims to fill this gap. Specifically, it will measure the physicochemical parameters of the watercourses, identify and count the BIMs and then establish correlations between the biodiversity of the BIMs and the state of health of the water.

2. Material and methods

2.1. Description of the study site

This study was carried out in the East Cameroon region with Bertoua as its capital. This region has an area of about 10,9002 km², an estimated population of 7,7755 inhabitants, for a density of 7.1 inhabitants/km 2 (5). Located between latitudes 3°49'599 North and longitude 14°10'0 East, the region is bordered on the left by the Centre and Adamaoua regions and on the right by the Central African Republic (14). The relief, which is part of the vast southern Cameroonian plateau with an average altitude of 650 m, is uneven in places due to isolated hills or hill complexes, variable slopes and the presence of some rocks (14). In addition, the eastern forest zone is characterised by "Xanthic" or "Plinthic Ferralsols" soils(FAO-UNESCO, 1976).

The climate is tropical humid, equatorial, with 4 well-marked seasons and uneven distribution (CVUC, 2018).



(**Source:** INC, data extracted from the topographic base 1/200000; 2020, modify)

Figure 1 Map showing surveyed rivers and sampling stations

The vegetation formation is low and medium altitude dense evergreen rainforest, consisting of old secondary forest, forest fallow dominated by Chomolaena odorata (48). The hydrographic network includes three major rivers (the Fala, So'o and Soumou) and the Nyong River (14).

Thus, two sub-basins were selected, namely the abong-doum sub-basin with two stream (Séna and Anzié) and 6 sampling stations (Sen1, Sen2, Sen3, Anz1, Anz2, and Anz3), and the Djenassoume sub-basin with two stream (Cours d'eau du chef and Djenassoume) and 6 sampling stations (Cdc1, Cdc2, Cdc3, Dje1, Dje2, and Dje3) (Figure 1).

2.2. Measurement of physicochemical parameter

For the physicochemical parameters, the physicochemical analysis were carried out both in the field and in the laboratory following the recommendations of APHA (4) and Rodier *et al.* (49).

Water temperature and pH were measured using a HANNA multimeter model HI 991301 and dissolved oxygen using a HANNA oximeter model HI 9829.

Parameters such as ammonia nitrogen, nitrates and phosphates were measured in the laboratory by colorimetry with a HACH DR/3900 spectrophotometer.

2.3. Collection and identification of benthic macroinvertebrates

The benthic macroinvertebrates were collected using a 30 cm square-shaped haze bucket, fitted with a conical net of 400 µm mesh opening and 50 cm depth. Sampling was carried out following the multihabitat approach proposed by Stark *et al.* (53). At each station, about 20 haul outs were carried out in different microhabitats over an area of about 3 m^2. The organisms retained by the net were then collected with a pair of fine tweezers, fixed in 10% formalin and preserved in pillboxes. On return to the laboratory, the samples were rinsed with running water and preserved in 70° alcohol. Identification of the organisms was carried out using a binocular magnifying glass, using the identification keys of Day *et al.* (16) and Tachet *et al.* (54).

2.4. Data analysis and statistical tests

The abundance and taxonomic richness of benthic macroinvertebrates were determined. In addition, the Shannon-Weaver index (H') was used to characterise the equilibrium of the population and the Piélou equitability index (J) to assess the equi-partition of taxa independently of the specific richness.

$H' = -\Sigma ((Ni/N) \times \ln (Ni/N))$; with Ni: number of individuals of a given species and N: total number of individuals.

$J = H'/Hmax = H'/Log2\ S$; with S: number of species observed.

The Kruskal-Walli's test allowed us to see if the results obtained vary significantly along the river and from one month to another, and the Mann Whitney U test to establish the differences between the stations. These three tests were carried out using PAST 3.0 software. As for Sörensen's similarity coefficient, which was calculated using ESTIMATE 9 software, it made it possible to evaluate the degree of similarity or dissimilarity of the benthic macroinvertebrate's population between the different stations, according to the formula

$$S = 2C/ (a+b) \times 100$$

S = similarity coefficient a: number of taxa present in the first station;
b = number of taxa present in the second station;
c = number of taxa common to both stations.

The typological approach was carried out using discriminant factor analysis (DFA) in order to identify the parameters that discriminate the different groupings by season (short dry season, short rainy season, long dry season, long rainy season). The approach consists of producing a series of discriminant variables, uncorrelated 2 by 2, so that observations belonging to the same group are as close as possible when projected onto the demographic axes, and those of different groups are far apart. Weights with an absolute value greater than |0.5| were more specifically considered (56). The Monte Carlo permutation test (n = 1000 random permutations) was performed to assess the reliability of the DFA (34). The DFA was performed using XLSTAT version 2021.2.

3. Results

3.1. Abiotic parameters

3.1.1. Temperature and pH

During the study period, the water temperature varied from 20.1 °C (January, And1) to 25.9 °C (May, Cdc2), with an average value of 22.56 °C ± 1.3 °C (Figure 2A). As for pH values, they vary between 3.3 CU (August, Sen1) and 9.06 CU (November, And 1) (Figure 2B), with an average value of 5.18 CU ± 0.30 CU.

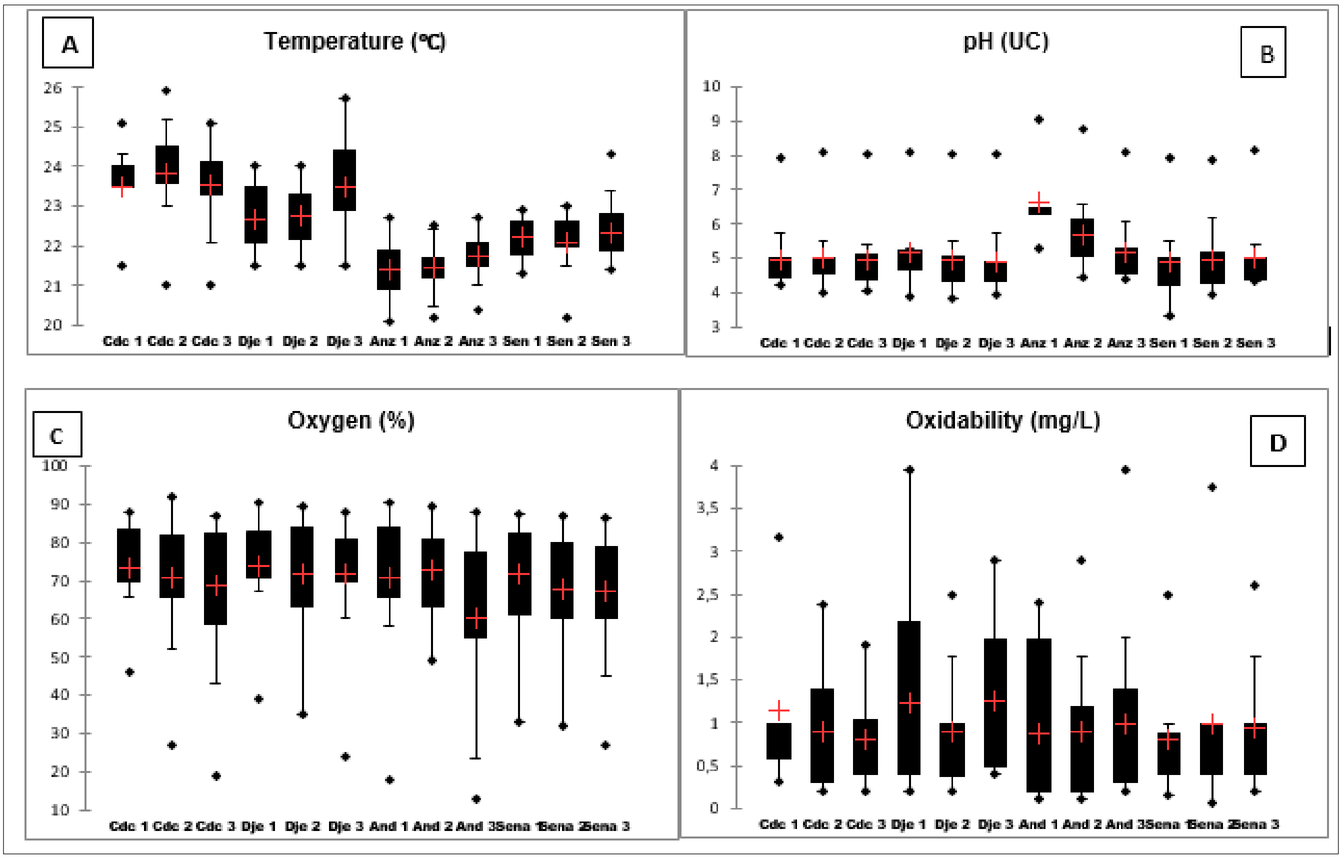
3.1.2. Oxygen and Oxidability

The maximum dissolved oxygen saturation (Figure 2C) is obtained in January (91.8% at Cdc2), and the minimum in December (13% at And3) with a mean value of 70.16% ± 4.08%. The maximum value of oxidability (Figure 2D) is obtained in April (3.95 mg/L at stations Dje1 and And3) and the minimum value in June (0.055 mg/L at station Sen2) with a mean value of 1.02 mg/L ± 0.36 mg/L.

3.1.3. Nitrates, Nitrites, Ammoniacal Nitrogen and Orthophosphates

The maximum levels of Nitrates and ammoniacal nitrogen (Figure 2E and 2F) are respectively 3.3 mg/L at station Cdc1 and 16 mg/L at station Cdc2 in February, the minimum values being respectively 0.01 mg/L in April at station Sen3 and 0 mg/L in September at station Sen1. The average values are around 0.75 ± 0.18 mg/L and 0.69 ± 0.34 mg/L respectively.

The maximum orthophosphate content (Figure 2G) is 4.95 mg/L in February at station And1, with a minimum value of 0 mg/L in November at all stations, for a mean value of 0.48 ± 0.21 mg/L.



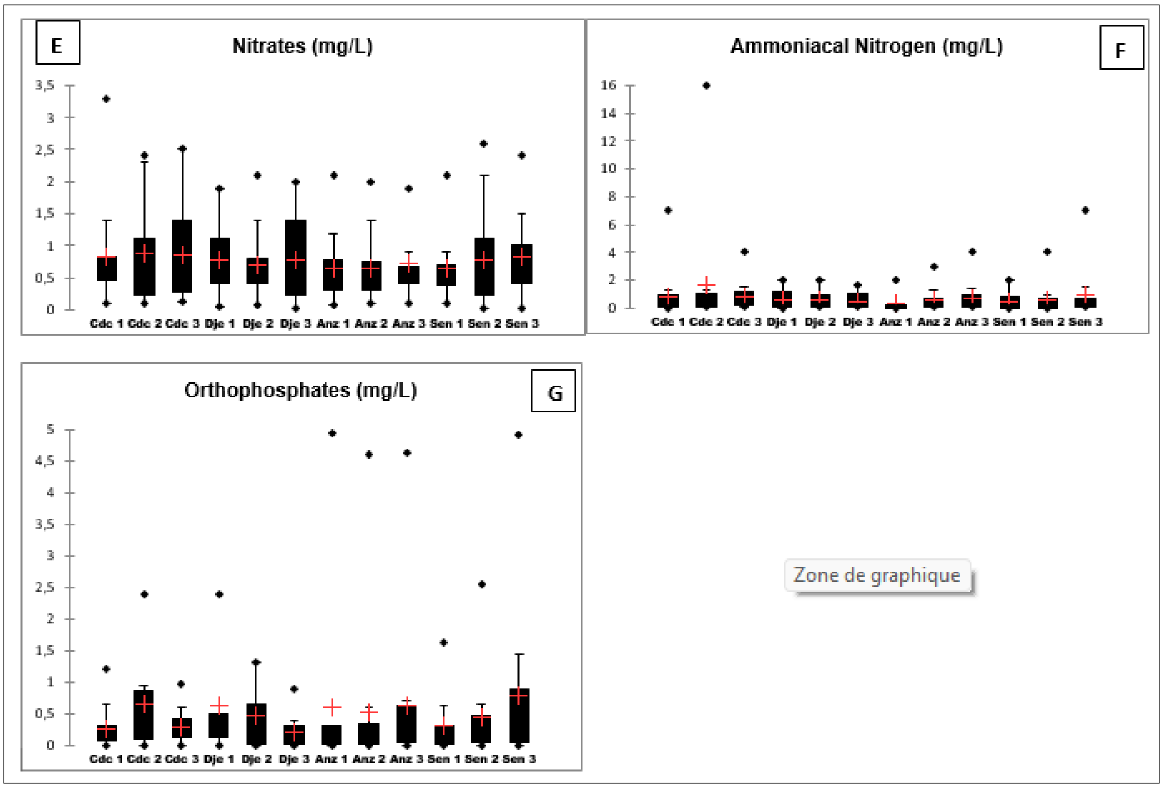


Figure 2 Variation of Temperature (A), pH (B), Dissolved Oxygen (C), Nitrate (D), Ammonium Nitrogen (E), Phosphate (F) and Oxidability (G) in streams during the study period

3.2. Biotic parameters

3.2.1. Taxonomic richness and abundance

Table 1 Relative and absolute abundance of benthic macroinvertebrates in the different stream during the study period

Stations	Absolute abundance	Relative abundance	Absolute abundance (average per river)	Relative abundance (average water course)
Cdc1	1209	9.62	3404	27.09
Cdc2	1034	8.23		
Cdc3	1161	9.24		
Dje1	1296	10.32	3067	24.42
Dje2	850	6.77		
Dje3	921	7.33		
And1	971	7.73	3298	26.3
And2	1364	10.87		
And3	963	7.7		
Sen1	1132	9.01	2789	22.19
Sen2	1390	11.06		
Sen3	267	2.12		
Totals	12558	100	12558	100

A total of 12558 individuals were collected, for a total abundance of 3404 individuals or 27.10% relative abundance in the CDC stream, 3067 individuals or 24.42% relative abundance in the Djenassoume stream, 3298 individuals or 26.26% relative abundance in the Anzié stream, and 2789 individuals or 22.28% relative abundance in the Séna stream (Table 1).

These organisms are divided into 3 phyla, including Arthropods (92.22%), Molluscs (7.36%) and Annelids (0.42%).

These phyla have 5 classes, 12 orders, 33 families and more than 56 genera/species. The Hexapoda class, which represents the most abundant taxonomic group with 7394 taxa, ethier 58.87% of relative abundance, has 8 orders, 26 families and 49 genera/species. It is followed by the Malacostracans with 4187 taxa, ethier 33.34% relative abundance, divided into 1 order, 3 families and 3 genera/species, followed by the Bivalves with 831 taxa, ethier 6.61% relative abundance. The other classes, notably the Gastropods with 94 individuals for 0.74% relative abundance and the Oligochaetes with 52 individuals corresponding to 0.40% relative abundance.

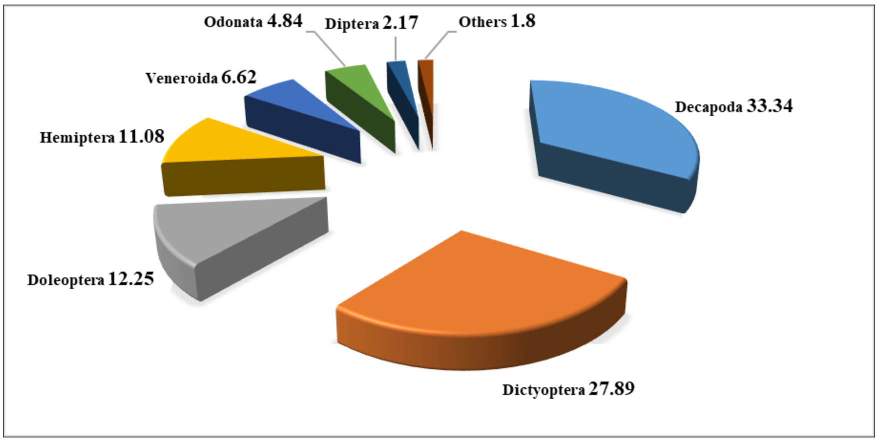


Figure 3 Relative abundance of different orders of benthic macroinvertebrates in the different streams during the study period

Among these organisms, the order Decapoda appears to be the most abundant with 4187 individuals, ethier 33.34% of relative abundance, followed by Dictyoptera with 27.55% of relative abundance, Coleoptera (12.08%), Hemiptera (11.26%), Eulamellibranchia (6.8%), Odonata (4.73%) and Diptera (2.18%). The other orders, namely Mesogasteroptera (0.75%), Haplotaxidae (0.42%), Ephemeroptera (0.34%), Trichoptera (0.24%) and Plecoptera (0.05%), are very poorly represented (Figure 2).

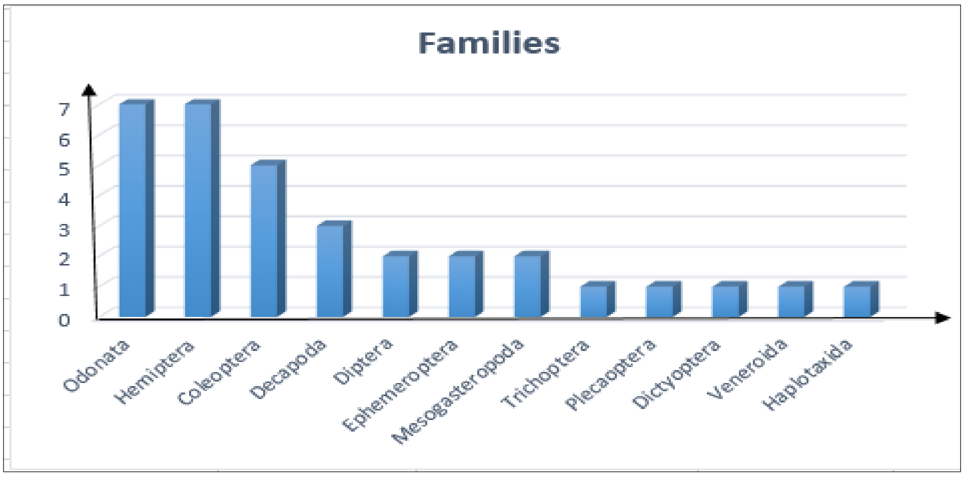


Figure 4 Taxonomic richness of benthic macroinvertebrates in the different streams during the study period

Relative and absolute abundance of macroinvertebrate families.

Of the 33 families inventoried, the orders Odonata and Hemiptera each have 7 families, followed by Coleoptera with 5 families and Decapoda (3 families). Diptera, Ephemeroptera and Mesogasteroptera have 2 families each, while Plecoptera, Trichoptera, Dictyoptera, Haplotaxidae and Veronidae have 1 family each (Figure 3).

In the <<Cours d’eau du Chef >> CDC stream, a total of 3404 individuals were counted (Table 2A), station Cdc1 has 1209 individuals distributed in 11 orders and 27 families dominated by the family Atyidae (28.45%), followed by Sphaeriidae (24.98%), Blaberidae (22.25%), Gyrinidae (6.36%) and Nepidae (3.14%), with 22 families being poorly represented. The 1034 individuals from station Cdc2 are divided into 12 orders and 27 families dominated by the family Atyidae (30.75%), followed by Sphaeriidae (23.8%), Blaberidae (19.92%), Libellulidae (3.38%), Gomphidae (3.15%) and Gyrinidae (3.77%), with 24 families being poorly represented. The 1161 individuals collected at station Cdc3 are divided into 9 orders and 23 families dominated by the family Blaberidae (31.78%), followed by the Atyidae (20.06%), Veliidae (17.83%), Sphaeriidae (12.23%), Gyrinidae (6.37%) and Gomphidae (3.96%), with 27 families being poorly represented.

In the Djenassoume stream, out of a total of 3067 individuals counted (Table 2B), at station Dje1 there were 1296 individuals divided into 9 orders and 24 families dominated by the family Atyidae (42.36%), followed by the Blaberidae (22.92%), Gyrinidae (9.49%), Nepidae (3.70%), Sphaeriidae (3.17%) and Gomphidae (3.16%) At station Dje2, a total of 850 individuals were recorded in 10 orders and 28 families dominated by the family Atyidae (38.59%), Blaberidae (25.65%) and Sphaeriidae (6.82%). As for station Dje3, out of a total of 921 individuals, divided into 8 orders and 22 families, the family Blaberidae dominates with (39.6%) relative abundance followed by the Atyidae (33.33%).

The Anzié stream has 3298 individuals (Table 2C) of which 971 were counted at the Anz1 station, distributed in 10 orders and 23 families dominated by the Blaberidae family (48.40%), followed by the Atyidae (23.17%). The Anz2 station has 1364 organisms distributed in 8 orders and 23 families dominated by the family Atyidae with 34.23% relative abundance, followed by the Blaberidae (28.89% relative abundance), the Veliidae (10.48%) and the Gyrinidae (9.68%). At the Anz3 station, out of a total of 963 individuals divided into 7 orders and 21 families, the family Atyidae dominated (39.56%), followed by Blaberidae (22.95%), Gyrinidae (9.97%) and Notoridae (5.81%).

At the Sena Stream (Table 2D), out of a total of 2789 individuals, the Sen1 station has 1132 individuals distributed in 9 orders and 25 families dominated by the Atyidae family (39.4%), followed by the Blaberidae (26.76%), and the Gyrinidae (13.07%). At the Sen 2 station, the 1390 organisms counted are divided into 11 orders and 26 families dominated by the family Atyidae (34.24%), followed by the Blaberidae (28.12%) and the Gyrinidae (9.56%). As for station Sen 3, the 267 individuals counted are distributed in 4 orders and 9 families dominated by the family Chironomidae (93.25% relative abundance).

Table 2 Distribution of the different families of benthic macroinvertebrates in the streams studied

[A]				
Families	**Stations**			**Total**
	Cdc1	**Cdc2**	**Cdc3**	
Atyidae	344(10.08%)	318(9.32%)	233(6.83%)	895(26. 23%)
Blaberidae	269(7.89%)	206(6.04%)	369(10.82%)	844(24.75%)
Sphaeriidae	302(8.86%)	246(7.21%)	142(4.16%)	690(20.23%)
Gyrinidae	77(2.25%)	39(1.14%)	24(0.70%)	140(4.10%)
Veliidae	27(0.79%)	6(0.17%)	207(6.07%)	240(7.03%)
Nepidae	38(1.11%)	5(0.14%)	21(0.61%)	63(1.84%)
Gomphidae	10(0.29%)	43(1.26%)	46(1.34%)	99(2.90%)
Libellulidae	9(0.26%)	32(0.93%)	14(0.41%)	55(1.61%)
Others famillies	133(3.90%)	140(4.10%)	111(3.25%)	384(11.26%)
Total	1209(35.45%)	1034(30.32%)	1167(34.22%)	3404(100%)

[B]				
Families	**stations**			**Total**
	Dje1	**Dje2**	**Dje3**	
Atyidae	549(17.90%)	328(10.69%)	307(10%)	1184(38.59%)
Blaberidae	297(9.49%)	218(7.10%)	365(11.90%)	880(28.69%)
Sphaeriidae	43(1.40%)	58(1.89%)	17(0.55%)	118(3.84%)
Gyrinidae	123(4.01%)	24(0.78%)	27(0.88%)	174(5.67%)
Veliidae	30(0.97%)	11(0.35%)	31(1.01%)	72(2.34%)
Nepidae	48(1.56%)	41(1.33%)	27(0.88%)	116(3.78%)
Gomphidae	41(1.33%)	28(0.91%)	11(0.35%)	80(2.60%)
Others famillies	165(5.37%)	142(4.62%)	136(4.43%)	443(14.44%)
Total	1296(42.26%)	850(27.72%)	921(30.02%)	3067(100%)

[C]				
Families	**stations**			**Total**
	Anz1	**Anz2**	**Anz3**	
Atyidae	225(6.82%)	467(14.16%)	381(11.55%)	1073(32.53%)
Blaberidae	470(14.25%)	394(11.95%)	221(6.70%)	1085(32.9%)
Gyrinidae	33(1%)	132(4%)	96(2.91%)	261(7.91%)
Veliidae	10(0.30%)	143(4.33%)	11(0.33%)	164(4.97%)
Nepidae	11(0.33%)	45(1.36%)	28(0.85%)	84(2.25%)
Hydrophilidae	24(0.72%)	10(0.30%)	44(1.33%)	78(2.36%)
Thiaridae	38(1.15%)	22(0.66%)	10(0.30%)	70(2.12%)
Others famillies	160(4.85%)	151(4.57%)	172(5.21%)	483(14.64%)
Total	971(29.44%)	1364(41.35%)	963(29.2%)	3298(100%)

[D]				
Families	**stations**			**Total**
	Sen1	**Sen2**	**Sen3**	
Atyidae	446(16%)	476(17.06%)	0	922(33.05%)
Blaberidae	303(10.86%)	391(14.01%)	0	694(24.88%)
Gyrinidae	148(5.30%)	133(4.77%)	0	281(10.07%)
Nepidae	36(1.29%)	59(2.11%)	0	95(3.40%)
Chironomidae	1(0.03%)	0	246(8.82%)	247(8.85%)
Others famillies	198(7.09%)	331(11.86%)	21(0.75%)	550(19. 72%)
Total	1132(40.59%)	1390(49.83%)	267(9.57%)	2789(100%)

3.2.2. Absolute abundance of some macroinvertebrate taxa

As the absolute and relative abundance of certain taxa is very low, only species with a relative abundance of at least 3% at one of the stations are taken into account in Figure 4.

Thus, 15 species were retained including 1 species belonging to the Crustacea class (Caridina africana), 12 to the Insect class (*Sympetrum fonscolombii, Cordulegaster maculata, Gomphus puchellus, Belostoma bakeri, Gerris* sp, *Ranatra linearis, Rhagovelia reitteri, Chironomus holomelas, orectochilus, Orechtogyrus specularis, Noterus* sp. and *Nd* (Blaberidae)), 1 species in the class Bivalves (*Sphaerium corneum*) and 1 species in the class Mesogasteropoda (*Lanistes lybicus*). The species *Chironomus holomelas* represented at station Sen3 (93%) and very weakly at Cdc1 and Cdc2 (less than 1%) are absent in the other stations, the species *Caridina africana* is dominant in the majority of the stations with relative abundances of Cdc1 (28%), Cdc2 (31%), Dje1 (42%), Dje2 (39%), Anz2 (34%), Anz3 (40%), Sen1 (39%) and Sen2 (34%) On the other hand, in the stations Cdc1 (25%) and Cdc2 (24%) the species *Sphaerium corneum* prevails with relative abundances. As for the unidentified species of the family Blaberidae their relative abundance comes after that of *Caridina africana* at stations Cdc3 (20%), Dje3 (33%) and Anz1 (23%). The other species are poorly represented.

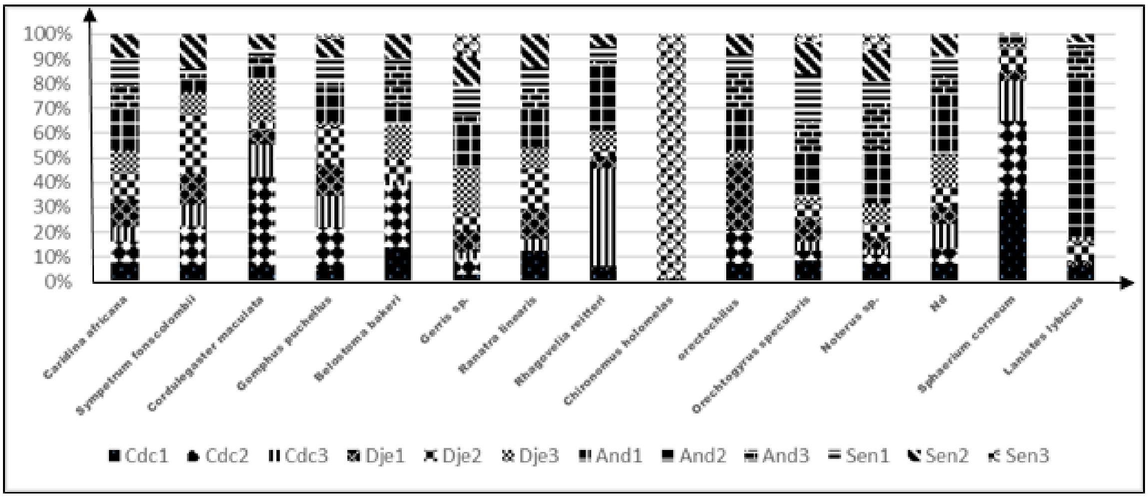
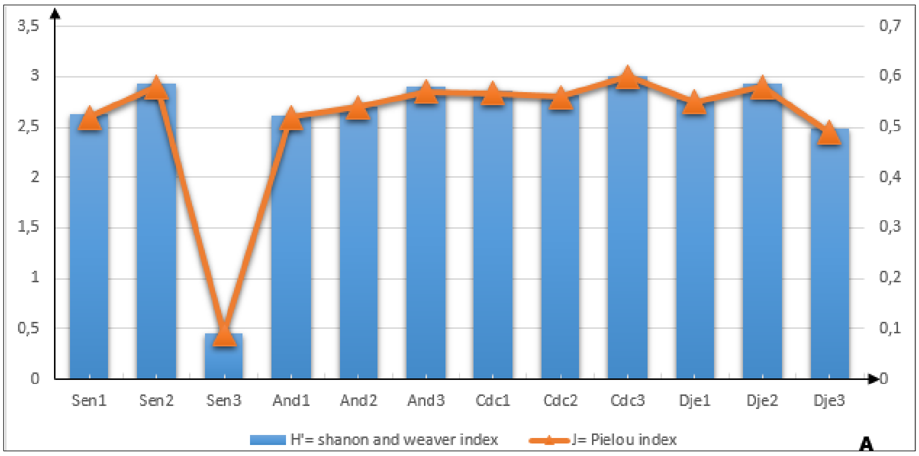


Figure 5 Spatial variation in the relative abundance of benthic macroinvertebrates species in the different streams during the study period

3.2.3. Shannon-Weaver diversity and Piélou equitability index

Spatially, the Shannon and Weaver diversity index is less than 1 at the only Sen3 station, indicating low biological diversity at this station (Figure 6A). The other stations have Shannon indices above 2.5. The most diverse station is Sen2 with a Shannon index of 3.27 bits/ind. Similarly, the highest value of the Piélou equitability index is found at the Sen2 station (0.56).



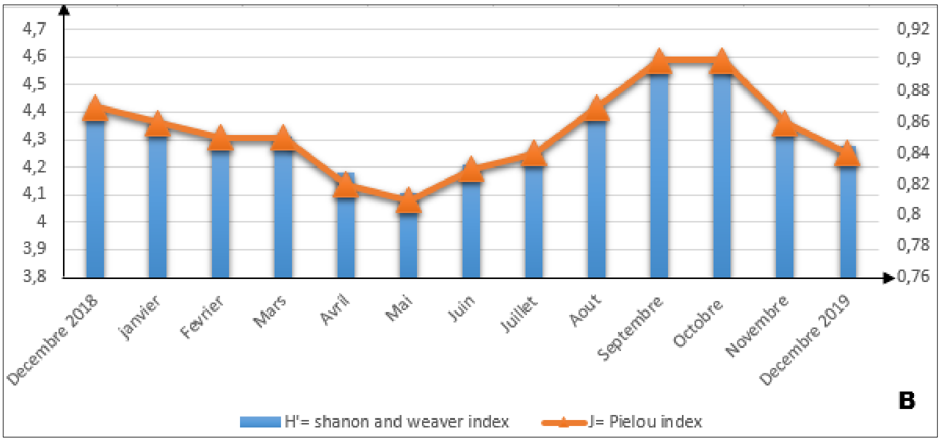


Figure 6 Spatial (A) and temporal (B) variations of the Shannon and Weaver index and the Piélou equitability index

In terms of time, the Shannon and Weaver diversity index has an almost similar evolution with a minimum value of 4.11 bits/ind. in May and a maximum value of 4.57 bits/ind. in September. In September. The highest value of the Piélou equitability index (0.9) is obtained in September and October and the lowest value (0.81) in May (Figure 6B).

3.2.4. Sörensen similarity index

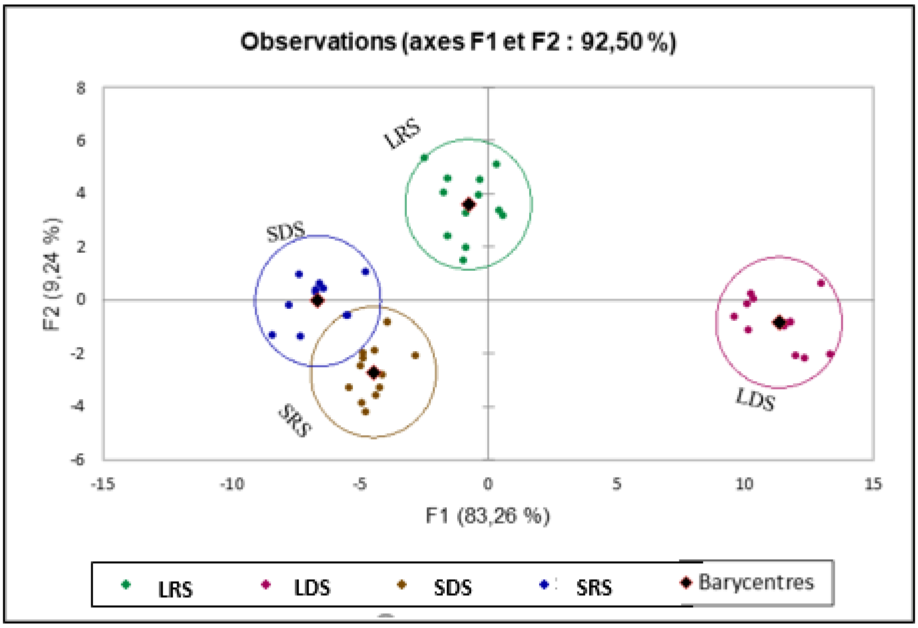
The taxonomic similarity rates between the macrobenthic populations collected at the different stations are presented in Table 4. However, these taxa are dissimilar at the other stations with very low similarity coefficients ranging from the lowest value of 18.2% (Sen3 and And1) to 42.1% for the pair (Sen3 and Dje3). In contrast, the taxa collected at the other pairs of stations show very high similarity rates, with values ranging from 68.9% for the pairs (Dje1 and Anz2; Dje1 and Anz3) to 85% (Sen2 and Dje1). On the other hand, the macrofauna inventoried at station Sen3 is dissimilar to those obtained at the other stations, as the similarity rates obtained are on the whole less than or equal to 43%. Overall, the Anzié, CDC and Djenassoume stream are very similar with a similarity coefficient of up to 84%.

Table 4 Values of the Sörensen similarity index between the different stations of the studied streams

	Cdc1	Cdc2	Cdc3	Dje1	Dje2	Dje3	And1	And2	And3	Sen1	Sen2	Sen3
Cdc1		84	70.8	76.1	77.1	76.2	72.5	78.1	75	77.8	77.9	27.9
Cdc2			76,1	83.1	81.6	72.5	82.7	71.4	74.3	74.4	84.3	28.6
Cdc3				76.5	74.6	76.7	75.8	68.9	68.9	69.6	75.7	0.3
Dje1					0.74	75.8	80.6	68.7	68.7	77.3	0.85	26.1
Dje2						70.8	76.1	72.7	72.7	70.3	78.5	26.7
Dje3							71.9	0.78	81.4	77.6	72.2	42.1
And1								73.8	73.8	0.74	79.5	18.2
And2									0.8	76.5	71.2	30.8
And3										82.4	0.74	30.8
Sen1											0.79	29.8
Sen2												23.1
Sen3												

A Discriminant Factor Analysis (DFA) is performed on the four seasons of the study area. This DFA was carried out on a matrix of mixed data on the presence/absence of taxa and environmental variables, in order to determine the environmental factors that influence the distribution of taxa within the different seasons defined. The two axes F1 (83.26%) and F2 (9.24%), which together account for 92.50% of the total inertia, were selected for ordination.

The factor map (Figure 6) obtained indicates that there is a similarity between the short dry season (SDS) and the short rainy season (SRS), while the long dry season (LDS) and the long rainy season (LRS) are clearly discriminated. The SDS, SRS and LRS are located on the negative side of the F1 axis and are clearly distinguished from the LDS which occupies the positive side of this axis. The F2 axis, on the other hand, opposes the LDS, SDS and SRS seasons located in negative coordinates, and the LRS season located in positive coordinates.



SDS: short dry season; SRS: short rainy season; LDS: long dry season; LRS: long rainy season

Figure 6 Discriminant Factor Analysis (DFA) showing the seasonal distribution of benthic macroinvertebrates in the F1 × F2 factorial design.

4. Discussion

Some of the work carried out in Cameroon on the benthic macrofauna shows that this fauna is subject to very little anthropic pressure, resulting in a low taxonomic richness. Thus, 12 orders, 33 families and 59 species were obtained in the same way as the work carried out by YOGBA (58) who obtained 12 orders and 45 families in the same region. This study also shows the abundance of certain taxonomic groups, notably insects and crustaceans. Similar observations were made in forest streams by Biram in Ngon (8), Yogba (58) and Mboye (40), with other groups such as Bivalves, Gastropods and Oligochaetes being poorly represented. The most abundant species are represented by Caridina Africana (4074 individuals), the family Blaberidae (3503 individuals) and Sphaerium corneum (831 individuals). Apart from the family Haplotaxidae, Mesogasteroptera, Plecoptera and Trichoptera are poorly represented.

The calculation of the Shannon and Weaver diversity index in the lower reaches of the Sena Stream (Sen3) shows a very low value due to the high abundance of the species Chironomus holomelas in this station (249), eithier 93.98% relative abundance. These results corroborate those of (22) and Levêque and Balian (31), according to which the Shannon & Weaver diversity index decreases when a taxon has a very high relative abundance. The same is true of Piélou's equitability index, which tends towards 0 at the same Sen3 station, indicating an imbalance in the macrobenthic population in favour of the emergence and dominance of the species Chironomus holomelas at this station. The high values of Sörensen's similarity index at stations Sen1, Sen2, Cdc3, Dje2, Dje3, And1, And2 and And3 show a high degree of similarity between the taxa at these stations. In addition, the high values of the Shannon and Weaver diversity index found in the other stream stations illustrate the perfect integrity of these hydrosystems. To this end, Fisher *et al.* (22) and Dajoz (15) state that the diversity index is all the higher when the environmental conditions favour the installation and maintenance of a balanced, integrated biological community capable of adapting to changes.

The high abundance of benthic macrofauna observed could be linked to the period of capture and the forest environment of the sites. In this respect, Mary (35) states that forested streams are favourable environments for the development of benthic macrofauna.

Furthermore, the diversification of the benthic macrofauna in these watercourses is favoured by the nature of the bed, which is essentially made up of coarse substrates that allow better adaptation of this macrofauna. This corroborates the results of Foto Menbohan *et al. (*23) in the Mabouinié; Liwouwou *et al. (*32) in the Rembo Bongo, Ogoué and Nyanga streams, which stipulate that the assembly of coarse substrates is favourable to aquatic life and to the maintenance of a greater biological diversity, reflecting the good ecological quality of the environment. In addition, the interstices between the alluvium allow the passage of water sprays ensuring continuous oxygenation limiting the risks of asphyxiation of sensitive species (29).

Similarly, the very low value of the Shannon & Weaver diversity index (H') and the Piélou equitability (J) observed at station Sen3 would indicate an unbalanced population, which is linked to the poor quality of the water maintained by the intense anthropic activity at this station. The balanced population (E>0.46) of the other stations is manifested by the non-existence of dominant taxa among the collected populations. In this regard, Death (17) and Massolou (36, 37), stating that habitat stability and biotic interactions could be important factors in the structure of macroinvertebrate communities.

Decapods, plecopterans, ephemeropterans and dictyopterans that tend to disappear when a stream becomes polluted are considered as indicator organisms (27). Therefore, the presence of Atyidae of the order Decapoda, in large the number of these species in several stations could reflect the good ecological health of these waters (3).

The Discriminant Factor Analysis (DFA) showed that the average values of water temperature coupled with high values of oxidability, contribute to the installation of a low diversity of benthic macroinvertebrates dominated by Melanoides tuberculata and, Oxygastra cutisii during the SDS, SRS and LDS. In contrast, during the LDS, the inversion of environmental conditions boosts taxonomic richness and creates a better distribution of benthic macroinvertebrate populations in the streams. In this regard, Colas *et al. (*13) point out that aquatic organisms integrate various types and degrees of environmental disturbances that occur on a variety of spatio-temporal scales; their structure then provides a much more accurate picture of the integrity of the hydrosystem (11).

Physicochemical factors condition life in the aquatic environment. Among these parameters, the most important are temperature and dissolved oxygen levels (23; 10). Indeed, water temperature influences the amount of oxygen and energy available for biological productivity and chemical processes necessary for aquatic life.

The relatively low temperature values (20.1 °C- 25.7 °C) recorded in the streams are thought to be due to the low penetration of sunlight into the streams. In this regard, Vanote *et al.* (57) point out that in streams in forested areas, the water temperature is low and varies little. These values are lower than those obtained by Tchakonté et al. (55), but close to those obtained by Biram (9) and Mboye *et al.* (39).

The pH data are relatively low (3.3 UC - 9.06 UC) and would be related to the nature of the bedrock. Indeed, Nola et al, (45) point out that the pH of the water is closely related to the nature of the soil in its catchment area. These results are similar to those obtained by Foto Menbohan *et al.* (24).

The studied streams show satisfactory oxygenation according to the water quality assessment grid proposed by Nisbet and Verneaux (44). The good oxygenation of the water can be explained by the presence of tree trunks that litter the bed of the watercourse, forming obstacles that favour mixing and consequently the enrichment of the water in oxygen. These results are similar to those of Biram (9) and corroborate those of Devidal *et al. (*18), according to whom in forested areas, natural ventilation, the presence of riffles and meanders create conditions of turbulence and mechanical mixing favourable to natural water aeration. However, the drop in values in December 2019 (LDS) observed in the majority of stations could be explained by the significant mineralising activity of microorganisms and the decrease in water flow.

The concentrations of nitrogenous nutrients and phosphates are low in all the streams. These results could be explained by the fact that the main sources of these elements are anthropogenic activities such as subsistence agriculture, livestock breeding, domestic activities and forestry, most of which still use archaic methods. Indeed, the main socio-economic activity practiced by the villagers is slash-and-burn agriculture, without the use of chemical fertilizers.

5. Conclusion

This work made it possible to characterise the benthic macrofauna of certain watercourses in the East Cameroon region, particularly in the villages of ABONG - DOUM and DJENASSOUME, and to assess their ecological quality. Generally speaking, these waters are acidic, well oxygenated and with low concentrations of nitrogen and phosphate matter. The count of benthic macroinvertebrates revealed 5 classes divided into 33 families, 12 orders and 58 species. Among these different classes, insects are the most abundant and diverse taxonomic group. As a result, the waters of the stations studied are of excellent ecological quality and do not currently seem to show any signs of disturbance, with the exception of the Sen3 station due to its proximity to villages and dwellings. In view of this, identification must be carried out down to the species level in order to have a complete physiognomy of the benthic macroinvertebrates of the forest streams in the East Cameroon region, as well as their ecological health. In addition, given the recurrence of logging projects in this region, it would be wise to assess the ecological health of these aquatic environments after logging and to propose plans for restoring the watercourses.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this document.

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